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ABSTRACT

The impregnation of building materials such as blocks and bricks with melted elemental sulphur increases the compressive strength by a factor of 2 and modulus of elasticity by a factor of 3. The permeability of sulphur impregnated materials to water and salt solutions is also greatly reduced. Due to the large surplus of sulphur and the low price, sulphur impregnation of building materials will find extensive use in tall building construction.

INTRODUCTION

General: Recently a huge oversupply of sulfur has developed as supply has overtaken demand. This oversupply of sulfur and sulfur equivalents will worsen as a result of environmental related desulfurization operations [1,2]. The price of sulfur is now dropped to its lowest level in 40 years. There is now a real economic incentive to the use of sulfur. This will also help to tackle world environmental problem by utilizing such an industrial waste by-product.

The advantages and practical aspects of using sulfur as a construction material have largely been overlooked in the past except for a short attempt in 1930's to erect various acid and corrosion proof chemical plant constructions [3,4,5]. Only very recently the interest has been focused on the structural use of sulfur as a binder material due to its excellent adhesion to other materials; substantial tensile strength, which can be improved with chemical modifiers; impermeability and ease of application to bind blocks and bricks for housing and construction [9]; to prevent reflective cracking in concrete pavements [10]; to coat mine walls for both sealing and supporting the weak areas [2]; and many other applications. Demonstration Housing Projects like the one in Guatemala under sponsorship of United Nations and other agencies have proven that construction with sulfur of house and shelter is not only feasible in the field but also economical for the developing countries to alleviate their housing problem with ease [9,14].

Use of Sulfur for Impregnation of Building Materials: Recent work done at our laboratory [8] and other places [7,17] as a continuation of fundamental and applied research in polymer impregnated concretes [7,8,17-23], have demonstrated the usefulness of sulfur as a cheap and yet equally effective substitute for polymers in concretes. The traditional approach for producing polymer impregnated concretes is to take previously-cured concrete, de-water it to vacate the void-system in the concrete and force a liquid monomer under pressure, which upon filling the void-structure, is thermal-catalytically polymerized to form solid interpenetrating network of polymer throughout the concrete. The concretes, now by virtue of solid in the pores, is not only impermeable to water and salt solutions, but have superb resistance to freezing-and-thawing chemical attack and abrasion. Moreover their compressive, tensile, and flexural strengths are 300% greater than those of unmodified concretes.

In spite of these advantages, the prices of the monomers prevent the large-scale structural use of polymer impregnated concrete and in the light of the shortage of oil there is no reason to believe that prices of monomers will decrease in the future. This makes sulfur very attractive for large-scale structural use. Other advantages of sulfur are that it melts at 113°C-120°C (235°F-248°F) and viscosity of molten sulfur remains relatively low, from about 12.5 centipose at 120°C to 6.6 centipose at 160°C (320°F). In this workable range, de-watered porous material can be impregnated with molten sulfur in the same manner as polymer impregnation, which upon cooling, solidifies to solid sulfur and fills up the pore structure. Compared to polymer-impregnation, there is the additional reduction in process cost with the elimination of polymerization step required in the polymer-impregnated concretes. Applications of sulfur impregnation, up til now were limited to concretes and ceramic tiles, which have shown 2 to 3 times improvement in strength and even better durability properties than polymer impregnated concretes with inherent chemical resisting properties of sulfur [7,8,16,17].

The purpose of this paper is to demonstrate for the first time the feasibility of impregnating other building materials such as bricks and blocks with a simple process and to evaluate their strengths and stress-strain characteristics in compression. The procedure and test results are described below.

EXPERIMENTAL

Materials: Fifty specimens of three different types of building blocks and 2 types of bricks, all locally manufactured, were procured. The blocks and bricks had nominal dimensions of 4"x8"x16" and 2"x4"x8" respecitvely. The cinder (CI series) and concrete blocks (C-series) were manufactured by Allentown Block

Manufacturing Company and the Waylite (W series) blocks were manufactured by Lehigh Block Manufacturing Company (Fig. 1a). Both, the solid tartan matte face bricks (Fig. 1b) and 3 holed, Dartmouth slurry face bricks (Fig. 1c) were manufactured by Glengary Brick Manufacturing Company.

The commercial grade flour sulfur was procured in 50 lb bags from George A. Rwoley Co., Inc. in Philadelphia. The important properties of this type of sulfur is that the solid has specific gravity of 2.08 and mainly has 2 allotropes α and β. The β phase has a specific gravity of 1.96 and melts at $119.3^{\circ}C$, the liquid molten sulfur has specific gravity of 1.803 and its viscosity decreases from 12.5 centipoise at $120^{\circ}C$ ($248^{\circ}F$) to 6.6 centipoise at $160^{\circ}C$ ($320^{\circ}F$). Above this temperature, sulfur becomes dark amber and highly viscous due to polymerization of S_4 molecules and this high viscosity would inhibit easy and quick infiltration. The temperature of molten sulfur was therefore kept between $121^{\circ}C$-$144^{\circ}C$ ($250^{\circ}F$-$290^{\circ}F$) throughout the impregnation process.

Impregnation Technique: The blocks and bricks were dried in the hot air oven at $300^{\circ}F$ for 2 hours and transferred to a propane fire torch heated steel vessel, half filled with melted sulphur and kept at between 250°-$280^{\circ}F$ (Fig. 2). The first four blocks and 2 bricks in each treated category (Table 1) were immersed for four hours and remaining specimens for 8 hours in molten sulfur. The specimens were then removed from the steel vessel, and excess liquid sulphur on the surface was wiped off. The samples were cooled in water for 20 minutes in order to crystallize the sulphur in the surface pores and prevent loss of sulphur by evaporation, and were then left at room temperature to cool in the air. The specimens were weighed before and after impregnation and sulphur loading calculated (Table 1). The impregnated specimens look shiny greenish to dark grey depending upon the original color of the specimens. However the rough texture is not very much affected. The total process time is 6-10 hours for both blocks and bricks.

Measurement of Physical Data: Table 1 lists all the weight data of blocks and bricks. The difference between the saturated and dry weight gives the percent weight gain with water and the difference between impregnated and dry weights give the percent weight gain with sulfur. It can be seen from the table that (1) porosity of blocks is roughly the same for 3 types of blocks with concrete blocks being more porous than the rest. In case of bricks, the Dartmouth bricks are nearly 40% more porous than solid bricks. This is also reflected in sulfur loading and individual strength measurement; (2) in general the percent weight gain for specimens immersed for 8 hours in molten sulfur is higher than those for 4 hours for all categories of blocks and bricks; (3) an average percent weight gain with sulfur for all type of blocks and bricks is a little more than twice the percent gain with water in accordance with their specific gravities (2.08 per sulfur vs. 1 for water) and proving that the pore volume previously filled with water can be completely occupied by sulfur; and (4) the scatter of individual weights of bricks and blocks are reflected in their strength and weight gain showing that blocks in particular do lack uniformity.

Preparation of Test Specimens: Seven days after the treatment of blocks and bricks, 4 specimens of control and all treated specimens of each category were made ready for capping.

Preparation of the individual block specimens involved the casting of hydrostone bearing caps on the upper and lower block surfaces at least 48 hours before testing. The choice of the capping material was based on its past satisfactory performance during comparable compression tests in which bearing pressures of 20,000 psi were encountered.

Some of the bricks and blocks in each category were strain gaged on 2 sides to measure the stress-strain behavior as shown in Fig. 1.

Test Procedure and Results: All specimens were tested in a universal hydraulic testing machine having a capacity of 800,000 pounds. The upper, movable head of the testing machine was fitted with a spherical bearing block in contact with a 2" thick machined plate resting on the upper surface of the specimen. The lower end of the specimen rested on a similar machined plate. Prior to the application of load all specimens were carefully aligned with the center of the bearing block.

Prior to application of load all specimens were carefully aligned with the center of the bearing block. The compressive load was then applied. The output of load from the machine and average strain from the gages were automatically recorded on an x-y plotter. From this load-strain curves, based on net bearing area, stress-strain curves were plotted and secant-modulus of elasticity at half the ultimate load were calculated.

The typical stress-strain curves for blocks and bricks are shown in Figs. 3, 4, 5 and 6, 7, respectively. Results of the compression tests of both the conventional and treated individual blocks and bricks are tabulated in Table 2. The ultimate stress ranged from 1403 psi to 2215 psi for untreated blocks as compared to 2889 to 8493 for treated blocks. The ultimate stress for untreated bricks ranged from 7,540 psi to 12,180 psi as compared to 15,620 to 25,230 psi for treated bricks.

The average sulfur loading, strength, and modulus of elasticity for different types of blocks and bricks as calculated in Tables 1 and 2 are summarized in Table 3 for comparison.

DISCUSSION OF TEST RESULTS

Table 3 clearly indicates that 2 fold increase in strength and 3 fold increase in modulus of elasticity can be achieved for sulfur impregnated blocks and bricks. This is rather significant considering the relative simplicity of impregnation procedure and cheap cost of sulphur material.

The stress-strain behavior of the untreated blocks versus treated blocks as shown in Figs. 3, 4 and 5 shows that for untreated specimens, the failure is similar to that of conventional concrete where the progressive failure of the interface between binder and aggregate, and then joining of cracks lead to a significant inelasticity of nonlinear stress-strain curve. However, for sulfurized blocks and bricks, the failure is similar to that of polymer impregnated concrete. The treated blocks and bricks explode and shatter completely upon failure. The stress-strain behavior is almost linear up to failure as those observed for polymer-impregnated materials with the traditional hook at the end. Sulfur treated blocks show a more brittle behavior with ultimate strain of only 40 to 70% of ultimate strain of untreated blocks. The treated bricks on the other hand achieved 85% of the ultimate strain of the untreated bricks.

APPLICATION TO LARGE-SCALE MANUFACTURE

The process developed here can be very conveniently and economically applied as an extension of brick and block manufacturing process. The block-specimens are already heated and dry as they come out of the curing process and can be immersed directly into molten sulfur. The bricks after they are fired and hot can be processed by immersing them directly into sulfur bath. The added material cost of sulfur will be approximately 2¢ for 2-3 lbs. of sulfur per block [24]. Thus with addition of 10-15% cost to manufacturing conventional bricks and blocks, an improvement of two to three times in strength, and modulus of elasticity can be obtained. Further, the impregnated materials are expected to have a very low water-permeability and very good durability. This is certainly worth considering for use in high-rise load bearing structures to mitigate world wide shortage of steel and cement and at the same time find a good use of this important industrial by-product: sulfur.

CONCLUSIONS

1. A simple impregnation process of blocks and bricks with liquid sulphur has been developed. After crytallization of the sulphur, 2 fold increase in compressive strength and 3 fold increase in modulus of elasticity have been found.
2. Sulfur is 20-40 times cheaper than conventional oil based thermoplastic polymers and it is available in large quantities. It is an effective substitute for large-scale polymer impregnation of building and structural materials [24].
3. Minimum equipment is required and the process can be included as an extension of the conventional bricks and block manufacturing process.
4. With an estimated 10-15% increase in manufacturing cost, sulfur-impregnation of building materials is the cheapest way yet found to increase strength and durability 2-3 times.
5. This new use of sulfur will permit a large-scale use of this important industrial by-product and will definitely be a step forward in providing new market for sulfur as an incentive to enhance industrial abalement of sulfur dioxide. It also helps to ease the environmental problems and shortage of steel and cement for housing.

REFERENCES

1. Meyer, B., "Future Uses of Sulfur", International Journal of Sulfur Chemistry, Part B, Volume 7, November 1972.
2. Dale, J. M. and Ludwig, A. C., "Sulfur Coatings for Mine Support", Final Report to U.S. Department of Interior, Bureau of Mines, Bureau of Mines open file report 31-73, November 1972.
3. Payne, C. R. and Duecker, W. W., "Chemical Resistance of Sulfur Cements," paper presented at the Providence, Rhode Island, AICE Meeting, Nov. 15-17, 1939, Trans., AICE (1940) 36(1), pp. 91-111.
4. Payne, C. R. and Duecker, W. W., "Construction with Sulphur Cement," Chem. and Mat. Eng., Vol. 47, 1940, p. 20.
5. Duecker, W. W. and Schofield, H. Z., "Results from the Use of Plasticized Sulphur as a Jointing Material for Clay Products", Bull. Am. Ceram. Soc., Vol. 16, 1937, p. 435.
6. Malhortra, V. M., "Mechanical Properties and Freeze Thaw Resistance of Sulfur Concrete," Department of Energy, Mines and Resources, Ottawa, 1973, Mines Branch Investigation Report IR 73-18.
7. Malhortra, V. M., Painter, K. E. and Soles, J. A., "Development of High Strength Concrete at Early Ages Using a Sulfur Infiltration Technique," paper prepared for presentation at the International Congress of Polymer Concretes, May 5-7, 1975, London, England.

8. Mehta, H. C., Chen, W. F., Manson, J. A. and Vanderhoff, J. W., "Innovations in Impregnation Techniques for Highway Concrete," paper prepared for presentation at the Annual Meeting of the Transportation Research Board, Washington, D. C., January 1975.

9. Testa, R. B. and Anderson, G. B., "The Use of Sulfur in Housing Construction: An Exploratory Study," report to Department of Civil Engineering and Engineering Mechanics, Columbia University, New York

10. Ludwig, A., "Sulfur Helps Crack Problem of Cracking Concrete," Chemical Marketing Newspaper, February 2, 1970.

11. Dale, J. M., "Sulphur-Fibre Coatings," Sulphur Institute Journal, 1965, p. 11.

12. Dale, J. M. and Ludwig, A. C., "Mechanical Properties of Sulfur Allotropes," Mat. Res. and Stds., v. 5, 1965, p. 411.

13. Dale, J. M. and Ludwig, A. C., "Feasibility Study for Using Sulphur-Aggregate Mixtures as a Structural Material," Southwest Research Institute, TR No. AFWL-TR-66-57, 1966.

14. Ludwig, A. C., "Utilization of Sulphur and Sulphur Ores as Construction Materials in Guatemala," Southwest Research Institute Technical Report, Project 01-2515-01, March 1969.

15. Crow, L. J. and Bates, R. C., "Strengths of Sulfur-Basalt Concretes," report to U.S. Department of the Interior, Bureau of Mines, 1970.

16. Kakos, M. J. and Fitzgerald, J. V., "Ceramic Tile," U.S. patent 3,208,190, Sept. 25, 1965.

17. Thaulow, N., "Sulfur-Impregnated Concrete, SIC, Cement and Concrete Research," Vol. 4, 1974, pp. 269-277.

18. Steinberg, M., et al, "Concrete Polymer Materials, Topical Reports 1 Through 5," Brookhaven National Laboratory and U.S. Bureau of Reclamation, December 1968-1973.

19. Chen, W. F. and Dahl-Jorgensen, E., "Stress-Strain Properties of Polymer Modified Concrete," Polymers in Concrete, American Concrete Institute Publication SP40-17, 1973, pp. 347-358.

20. Cohan, H. J., FHWA Contract No. PO-2-1-1214, "Surface Impregnation of Concrete Bridge Decks," U.S. Bureau of Reclamation, Progress Reports, 1973.

21. Dahl-Jorgensen, E., Chen, W. F., Manson, J. A. and Vanderhoff, J. W., "Polymer-Impregnated Concrete: Laboratory Studies," presented at the ASCE-EIC/RTAC Joint Transportation Convention, Montreal, Quebec, July 1974.

22. Mehta, H. C., Manson, J. A., Chen, W. F. and Vanderhoff, J. W., "Polymer-Impregnated Concrete: Field Studies," presented at the July 15-19, 1974, ASCE-EIC/RTAC Joint Transportation Convention, Montreal, Quebec.

23. Manson, J. A., Chen, W. F., Vanderhoff, J. W., Liu, Y. N., Dahl-Jorgensen, E. and Mehta, H. C., "Stress-Strain Behavior of Polymer-Impregnated Concrete," Polymer Preprints, Vol. 14, No. 2, August 1973, pp. 1203-1208.

24. Chemical Marketing Report, Schnell Publishing Company, Inc., New York, September 30, 1974.

TABLE 1 WEIGHT AND PERCENT LOADING DATA FOR BLOCKS AND BRICKS

	Specimen No.	Ambient Weight (lbs)	Water Saturated Weight(a) (lbs)	Dry Weight(b) (lbs)	Water Weight Gain (%)	Weight After Sulfurization (lbs)	Sulfur Weight Gain (%)
Concrete Blocks	TC1	22.00	23.30	21.30	9.39	25.60	20.19
	TC2	23.50	24.20	22.10	9.50	26.70	20.81
	TC3	23.20	24.40	22.30	9.42	--	--
	TC4	23.35	24.60	22.50	9.33	--	--
	TC5	25.05	26.00	23.70	9.70	--	--
	TC6	25.25	26.00	23.70	9.70	--	--
	TC7	22.20	23.15	21.10	9.72	25.30	19.91
	TC8	23.10	24.35	22.00	10.68	26.50	20.45
	TC9	23.10	--	22.50	--	27.70	23.11
	TC10	23.00	--	22.20	--	27.70	24.77
	TC11	25.30	--	23.90	--	29.20	22.18
	TC12	25.25	--	22.20	--	27.60	24.32
	Average	23.69	24.50	22.46	9.68	27.04	22.61
Waylite Blocks	TW1	20.20	22.00	20.10	9.45	24.50	21.39
	TW2	20.00	21.90	19.90	10.05	24.80	24.62
	TW3	20.20	22.00	19.80	11.11	24.70	24.75
	TW4	21.15	22.90	20.60	11.17	25.50	23.79
	TW5	21.00	23.30	20.70	12.56	26.20	26.57
	TW6	19.95	22.20	19.60	13.27	25.45	29.85
	TW7	21.10	23.10	20.45	12.96	25.75	26.16
	TW8	20.50	22.70	20.20	12.38	25.40	25.74
	Average	21.24	22.51	20.17	11.62	25.29	25.36
Cinder Blocks	TCI1	20.00	21.05	18.80	11.97	--	--
	TCI2	20.20	21.35	19.10	11.78	--	--
	TCI3	19.70	20.40	18.40	10.86	--	--
	TCI4	20.20	21.35	19.20	11.20	--	--
	TCI5	18.60	19.70	17.60	11.93	--	--
	TCI6	19.40	20.40	18.30	11.47	--	--
	TCI7	18.65	19.70	17.55	12.25	--	--
	TCI8	20.00	21.25	19.00	11.84	--	--
	TCI9	18.80	--	17.65	--	21.80	23.51
	TCI10	18.80	--	17.40	--	21.80	25.28
	TCI11	19.05	--	17.90	--	22.20	24.02
	TCI12	20.00	--	19.05	--	23.70	24.40
	TCI13	19.40	--	18.15	--	23.00	26.72
	TCI14	19.40	--	18.20	--	23.10	26.92
	TCI15	19.70	--	18.30	--	22.90	25.13
	TCI16	19.75	--	18.60	--	23.50	26.34
	Average	19.53	20.65	18.33	11.66	22.75	25.29
Solid Bricks	TB1		5.181	4.907	5.58	5.532	12.73
	TB2		5.254	4.923	6.73	5.536	12.46
	TB3		5.570	5.234	6.41	4.857	13.87
	TB4		5.611	5.291	6.05	6.029	13.93
	Average		5.404	5.088	6.19	5.764	13.24
Dartmouth Bricks	TD1		5.128	4.748	8.00	5.377	13.24
	TD2		5.252	4.837	8.58	5.720	18.25
	TD3		5.320	4.879	9.05	5.746	17.78
	TD4		5.325	4.945	7.68	5.817	17.63
	Average		5.256	4.852	8.33	5.664	16.73

a. Blocks are immersed in water for 48 hours
b. Specimens dried for 24 hours at 300°F for drying tests

TABLE 2 RESULTS OF COMPRESSION TESTS ON INDIVIDUAL BLOCKS AND BRICKS

	Specimen No.	Sulfur Loading (%)	Ultimate Load (lbs)	Ultimate Stress (psi)	Remarks
Concrete Blocks	C1		90,250	2317	length = 15.836"
	C2		106,250	2728	breadth = 3.6"
	C3		126,250	3241	height = 7.535"
	C4		94,000	2413	net bearing area = 38.95 in^2
	Average		104,187	2675	gross bearing area = 57.01 in^2
	Treated				gross volume = 429.57 in^3
	TC7	19.91	181,750	4666	
	TC8	20.45	260,500	6688	
	TC10	24.77	328,700	8439	
	TC12	24.32	330,000	8472	
	Average		275,237	7066	
Waylite Blocks	Control				
	W1		92,500	2309	length = 15.744"
	W2		82,500	2060	breadth = 3.623"
	W3		83,500	2085	height = 7.590"
	W4		80,000	1997	net bearing area = 40.054 in^2
	Average		84,625	2113	gross bearing area = 57.04 in^2
	Treated				gross volume = 432.93 in^3
	TW1	21.39	170,000	4244	
	TW2	24.62	150,000	3745	
	TW5	26.57	128,000	3203	
	TW7	26.16	115,700	2889	
	Average		140,750	3520	
Cinder Blocks	Control				
	CI1		88,000	2314	length = 15.903"
	CI2		80,000	2104	breadth = 3.6"
	CI3		82,000	2156	height = 7.756"
	CI4		82,500	2169	net bearing area = 38.03 in^2
	Average		83,130	2186	gross bearing area = 56.89 in^2
	Treated				gross volume = 441.25 in
	TCI11	24.02	140,000	3681	
	TCI12	24.40	172,400	4533	
	TCI13	26.72	197,000	5180	
	TCI14	26.92	167,000	4391	
	Average		169,000	4446	
Solid Brick	Control				
	B1		320,000	11,200	length = 8.0"
	B2		348,000	12,180	breadth = 3.57"
	B3		300,000	10,500	height = 2.21"
	Average		322,670	11,293	net bearing area = 28.56 in^2
	Treated				gross bearing area = 28.56
	TB2	12.46	563,000	21,200	gross volume = 63.18 in^3
	TB4	13.93	720,600	25,230	
	TB3	13.87	692,200	24,260	
	TB1	12.73	683,600	23,940	
	Average		664,850	23,653	
Dartmouth Brick	Control				
	D1		304,000	11,2[illegible]	length = 8.07"
	D2		206,000	7,540	breadth = 3.53"
	D3		261,000	9,550	height = 2.26"
	Average		257,000	9,430	net bearing area = 27.33 in^2
	Treated				gross bearing area = 28.48 in
	TD4	17.63	448,000	16,390	gross volume = 61.94 in
	TD1	13.24	427,000	15,620	
	TD2	18.25	620,000	22,690	
	TD3	17.78	439,000	16,060	
	Average		483,500	17,600	

TABLE 3 SUMMARY OF IMPROVEMENT IN STRENGTH AND MODULUS OF ELASTICITY FOR BLOCKS AND BRICKS (a)

Type	(Water) Sulfur Loading (%)	Compressive Strength psi	Ultimate Strain 10^{-6}	Secant Modulus (b) 10^{6}, psi
Concrete Control	(9.68)	2675	2000	1.830
Block Treated	22.61	7066	1600	6.225
Percent Change (c)	234	264	70	342
Waylite Control	(11.62)	2113	1760	1.563
Block Treated	25.36	3520	660	5.000
Percent Change	218	167	38	320
Cinder Control	(11.66)	2186	1900	1.716
Block Treated	25.29	4446	1250	5236
Percent Change	217	203	66%	305
Solid Control	(6.19)	11,293	2500	3.660
Brick Treated	13.24	23,653	2100	10.280
Percent Change	214	209	84	281
Dartmouth Control	(8.33)	9430	2200	4.277
Brick Treated	16.73	17,600	1880	9.091
Percent Change	201	187	85	213

(a) Average, obtained from tables 1 and 2

(b) Secant modulus measured by dividing stress by strain at ½ the ultimate load

(c) Percent change = (treated/control) x 100

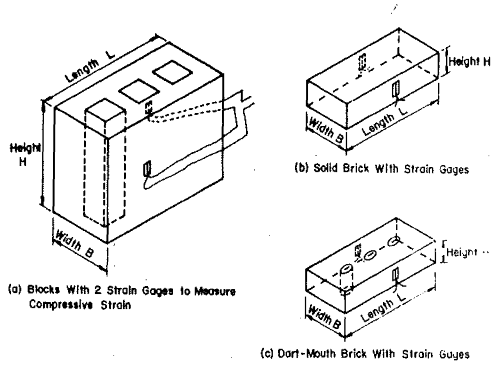

Fig. 1 Types of Blocks Used for Sulfur-Impregnation

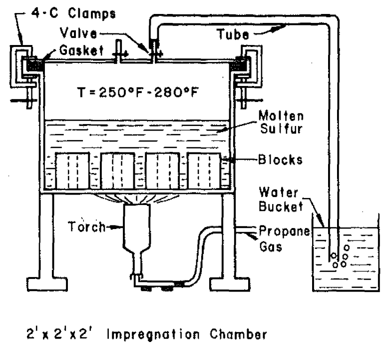

Fig. 2 Impregnation Procedure used in the Laboratory

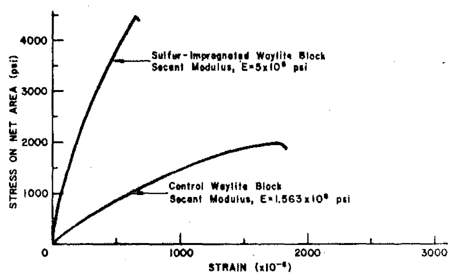

Fig. 3 Stress-Strain Curve for Waylite Blocks

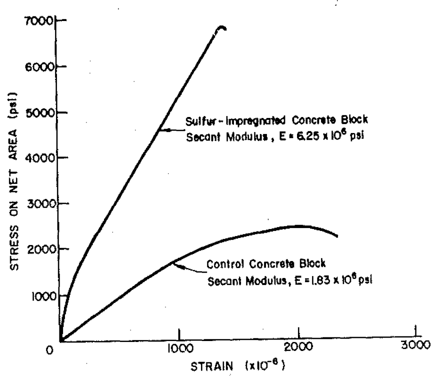

Fig. 4 Stress-Strain Curve for Concrete Blocks

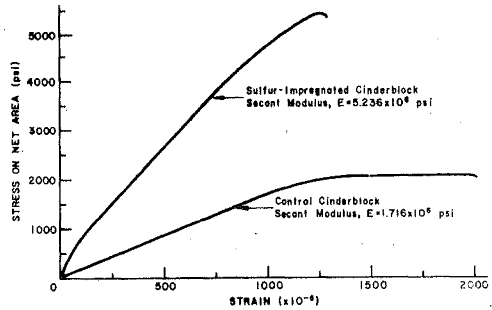

Fig. 5 Stress-Strain Curve for Cinder Blocks

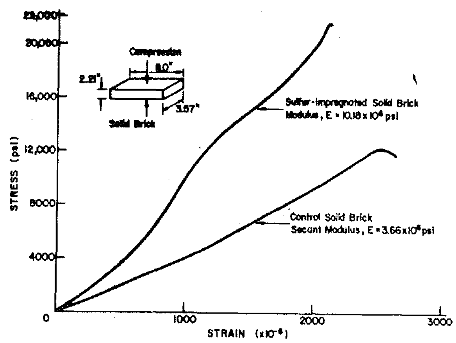

Fig. 6 Stress-Strain Curve for Solid Bricks

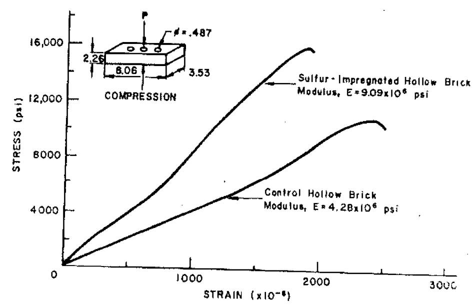

Fig. 7 Stress-Strain Curve for Dartmouth Bricks